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Atrazine distribution measured in soil and leachate following infiltration conditions

Susan K. Neurath [a,1], Ali M. Sadeghi [b,*], Adel Shirmohammadi [c],
Allan R. Isensee [b], Alba Torrents [a]

[a] *Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, USA*
[b] *USDA-ARS, Animal and Natural Resources Institute, Environmental Quality Laboratory, Beltsville, MD 20705, USA*
[c] *Biological Resources Engineering Department, University of Maryland, College Park, MD 20742, USA*

Abstract

Atrazine transport through packed 10 cm soil columns representative of the 0–10 cm soil horizon was observed by measuring the atrazine recovery in the total leachate volume, and upper and lower soil layers following infiltration of 7.5 cm water using a mechanical vacuum extractor (MVE). Measured recoveries were analyzed to understand the influence of infiltration rate and delay time on atrazine transport and distribution in the column. Four time periods (0.28, 0.8, 1.8, and 5.5 h) representing very high to moderate infiltration rates (26.8, 9.4, 4.2, and 1.4 cm/h) were used. Replicate soil columns were tested immediately and following a 2-d delay after atrazine application. Results indicate atrazine recovery in leachate was independent of infiltration rate, but significantly lower for infiltration following a 2-d delay. Atrazine distribution in the 0–1 and 9–10 cm soil layers was affected by both infiltration rate and delay. These results are in contrast with previous field and laboratory studies that suggest that atrazine recovery in the leachate increases with increasing infiltration rate. It appears that the difference in atrazine recovery measured using the MVE and other leaching experiments using intact soil cores from this field site and the rain simulation equipment probably illustrates the effect of infiltrating water interacting with the atrazine present on the soil surface. This work suggests that atrazine mobilization from the soil surface is also dependent on interactions of the infiltrating water with the soil surface, in addition to the rate of infiltration through the surface soil.
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1. Introduction

Understanding solute sorption and retardation is an important component of assessing and modeling solute transport into and through the upper soil layers. The United States Department of Agriculture (USDA) at the Beltsville Agricultural Research Center, has studied the fate and transport of several herbicides, commonly used in corn production (Isensee et al., 1990; Isensee and Sadeghi, 1994; Sadeghi et al., 1995; Sadeghi and Isensee, 1996). Results of the field studies indicate that rainfall amount and intensity, and the delay between herbicide application and the first rainfall event significantly effect the amount of atrazine measured in unconfined shallow ground water (Isensee et al., 1990; Isensee and Sadeghi, 1995), and its distribution in the 0–50 cm soil horizon (Sadeghi and Isensee, 1992; Isensee and Sadeghi, 1994).

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*Corresponding author. Address: USDA-ARS, Environmental Quality Laboratory, Barc-West Building 007, Beltsville, MD 20705-2350, USA. Tel.: +1-301-504-6693; fax: +1-301-504-5048.

E-mail address: sadeghia@ba.ars.usda.gov (A.M. Sadeghi).
[1] Currently with the US EPA in Georgia.

Laboratory leaching studies using intact cores (10 cm diameter, 8 cm depth) from this field and a rainfall simulator apparatus also indicate that the amount of atrazine in the leachate increased with rainfall intensity (Sigua et al., 1993), and decreased as the delay between application and rainfall increased (Sigua et al., 1995).

Laboratory leaching studies using column breakthrough experiments provide estimates of sorption and transport parameters under flow conditions and are therefore more likely to represent atrazine transport under field conditions. For these experiments the mechanical vacuum extractor (MVE) was used to draw the infiltration water through a packed soil column dosed with atrazine. The resulting leachate volume and samples of the upper-most and lower-most soil layer were analyzed for atrazine recovery. The measured atrazine recovery in these locations was used to evaluate atrazine mobilization from the soil surface, deposition on the lower soil layer and leachate concentration under various infiltration conditions.

The purpose of this work was: (i) to identify the effect of infiltration rate and delay on atrazine transport through the 0–10 cm soil horizon; (ii) to evaluate how variations in infiltration rate and delay effected atrazine mobilization from the soil surface; and (iii) to compare results from the MVE to those measured from leaching experiments using intact soil cores under simulated rainfall conditions.

2. Materials and methods

2.1. Mechanical vacuum extractor

The MVE was used to draw infiltration water through a soil column and collect the leachate. Fig. 1 shows the column test apparatus. It consists of three syringes held vertically in place by three horizontal circular plates. The center syringe contains the packed soil column. The upper syringe is the infiltration reservoir and is held in place at the top of the center syringe by an airtight seal. The bottom syringe is the leachate collection chamber and is also connected to the center syringe by an airtight seal. Prior to beginning infiltration the plunger of the leachate collection syringe is fully inserted into the leachate collection syringe. The bottom tip of the soil packed center syringe is attached to the top tip of the leachate collection syringe using a small piece of rubber tube. This unit is attached to the three MVE plates and then the infiltration reservoir syringe is added. The two upper plates stabilize the syringe system and the lower plate pulls down the plunger of the leachate collection syringe at a constant rate.

As the plunger is pulled down a vacuum is created in the leachate collection syringe. This draws fluid (air or leachate) from the soil column. This in turn creates a
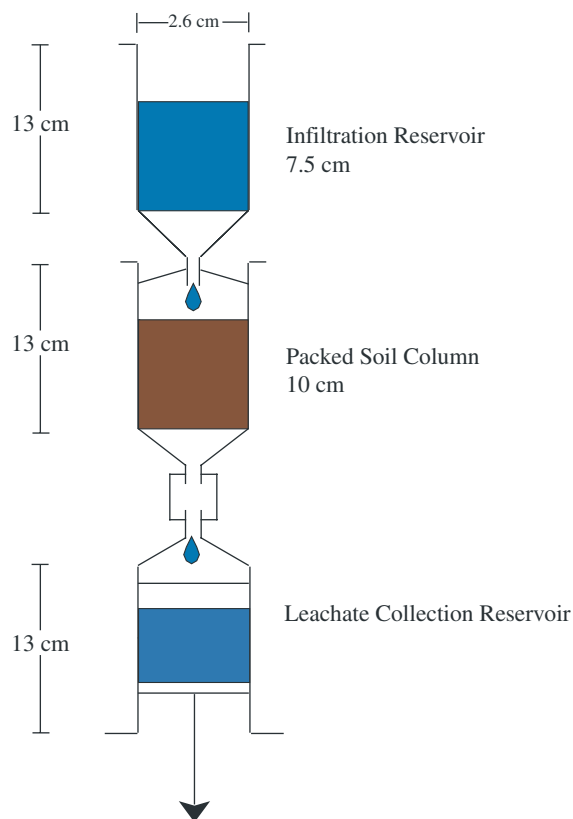

Fig. 1. Illustration of experimental set-up for column leaching experiments using the MVE. The MVE controls the continuous movement of the plunger downward at the desired rate. The suction created in the collection reservoir draws water from the infiltration reservoir through the soil column. This system was used to simulate atrazine leaching from the soil surface through the 10 cm column under various conditions, as described in the text.

vacuum in the soil column that draws infiltration water from the infiltration reservoir. The infiltration rate is dependent on the speed at which the plunger is moved. Once set, the plunger speed was held constant for the duration of the test. The infiltration reservoir holds approximately 80 ml of fluid. The complete fluid volume can be drawn through the soil column over a period of 15 min to 12 h.

2.2. Soil column preparation

Soil samples used to pack the columns were obtained from the Southfarm field site located at the USDA's Beltsville Agricultural Research Center. The 1.37-ha site is situated in an alluvial valley in the Coastal Plain region. Site characteristics and treatment history have previously been described (Sadeghi and Isensee, 1992; Isensee and Sadeghi, 1996). Soil samples were collected

from the 6-year old field plot that has been under no-till (NT) corn production. The dominant soils are Iuka silt loam (coarse-loamy, siliceous, acid mesic Aquic Udifluvents) and Hatboro silt loam (fine-loamy, mixed, nonacid, mesic Typic Fluvaquents) (Sadeghi and Isensee, 1992).

Soil samples (2 cm dia. by 10 cm deep) were removed with a hand-coring tool and divided into three sections (0–3, 3–6, 6–10 cm). Soil samples of each section were mixed together. Approximately 20 individual soil samples were pooled together by section. The soil from each section was air dried to an approximate gravimetric moisture content of 10% (12.1%, 7.4%, and 7.7% respectively for the 0–3, 3–6, 6–10 cm sections) and hand sieved (5.7 mm). Dried sieved soil was placed in sealed glass jars and stored at room temperature until used in the column experiments. Storage time varied from approximately 2 d to 2 weeks.

The body of the syringes has an inner diameter of approximately 2.6 cm and is 13 cm long (Fig. 1). Each syringe was hand-packed with soil to create homogenous soil columns and encourage matrix flow conditions through soil profiles representative of the bulk field properties for the 0–10 cm soil horizon (density, organic carbon, and texture). The desired density of the soil column was 1.45 g/cm^3 (a typical bulk density value for silt loam soils, a dominant soils in Beltsville Agricultural Research Center's Southfarm corn production plots). Columns were packed by first adding 30.8 g of soil from the 6–10 cm section. The soil was gently poured into the syringe. After half of the soil was added, the bottom tip of the syringe was gently tapped against the bench top to lightly pack the soil. The soil surface was then scratched with a needle prior to pouring in the remaining amount of the 6–10 cm soil aliquot. The 0, 3, and 6 cm depths were marked on the outside of the syringe body. After all of the 6–10 cm soil was added to the syringe, the bottom tip was again tapped against the bench top until the soil surface was even with the 6 cm depth mark. The soil surface was again scratched prior to adding 23.1 g of soil from the 3–6 cm section.

Soil from the 3–6 and 0–3 cm sections was added in the same manner. The soil surface was scratched following each compaction (tapping) step to discourage the formation of layer boundaries. The columns were typically packed 1–2 d prior to atrazine application. Prior to use, they were stored in the lab, covered with plastic wrap to prevent desiccation.

With bulk density (ρ_b) of the packed columns being 1.45 g/cm^3 and assuming a particle density (ρ_p) of 2.65 g/cm^3 for the soil material; the porosity (n) of the packed soil column can be estimated by (Fetter, 1994):

$$n = 100(1 - \rho_b/\rho_p) = 100(1 - 1.45/2.65) \sim 45\%$$

The pore volume (V_{pore}) of the packed soil column can be estimated by (Fetter, 1994):

$$V_{pore} = nV$$

where V is the total soil volume (2.6 cm dia. × 10 cm length; $V = 53.1$ cm^3). The resulting pore volume is approximately 23.9 cm^3.

2.3. Experimental procedure

The infiltration tests were performed for four different time periods ($T_{Leach} = 0.28, 0.8, 1.8,$ and 5.5 h). For each T_{Leach} the amount of water leached from the infiltration reservoir into the soil column was constant (7.5 cm = 42 ml, approximately 1.76 pore volumes). This resulted in infiltration rates (I) of 26.8, 9.4, 4.2, and 1.4 cm/h. For each T_{Leach}, eight columns were dosed with 0.560 ml of the commercial atrazine formulation, Aatrex Nine-O, in deionized water (DI). Dose solutions were prepared fresh prior to use; therefore atrazine concentration in the solution varied from 138.4–176.1 mg/l. All of the columns for a particular T_{Leach} experiment were dosed at the same time, from the same dose solution. Therefore the atrazine application rate to the soil surface varied from 1.46 to 1.86 kg/ha, which is within the range used on the field at this test site. The goal of this procedure was to simulate, as close as possible, field application of atrazine.

After atrazine was applied to all eight columns used for one T_{Leach} test, four of the columns were set-up in the MVE and immediately leached at one of the four infiltration rates; these results are identified as the "immediate" tests. The other four columns were stored vertical, open to room air, on the lab bench. They were leached by the same conditions used for the corresponding immediate tubes, but after a 2-d delay, and are identified at the "delayed" tests.

The leaching experiments were terminated when all of the infiltration volume had been drained from the infiltration reservoir. At the end of the test the leachate reservoir contained both air and leachate. The total volume of fluid in the leachate reservoir was equivalent to the water volume drained from the infiltration reservoir. However the leachate reservoir did not contain all of the infiltration solution. During the early stages of the leach test, air was drawn from the soil into the leachate collection reservoir. Therefore, at the end of the leach test some of the infiltration solution remained in the soil column.

2.4. Sample analysis

At the completion of the leaching experiment a sample of the leachate was filtered (0.2 μm, Nuclepore Polycarbonate) into a 1-ml glass HPLC vial and sealed with an LDPE cap. Samples of the 0–1 cm soil layer were obtained by removing approximately 4 g of material from the center of the soil surface. Samples from the

9–10 cm layer were obtained by inverting the syringe and allowing the entire soil column to slide out. Due to the high water content, the 9–10 cm layer was easily distinguished. Each soil sample was placed into a tared 15-ml polypropylene tube and reweighed. The atrazine in the soil sample was extracted by adding 8 ml HPLC grade methanol to the tube. The capped tube was hand shaken to disperse the soil into the methanol and then placed on an end-over-end rotator (40 RPM) to equilibrate for 90 min. Preliminary studies indicated that atrazine removal was similar for equilibration times of 1 and 24 h.

After equilibration the tubes were centrifuged (Bechman GPR) at approximately 3000 RPM for 20 min. The supernatant was filtered (0.45 μm, Acrodisc 13 CR PTFE) into 1-ml glass HPLC vials. The atrazine concentration in both the leachate and soil extractions was measured by HPLC. The solvents were 0.55 ml/min acetonitrile and 0.45 ml/min phosphoric buffer (1% phosphoric acid in DI) using Waters 510 HPLC pumps. The column was an Altima C18 5 μm, 150 mm long, and a Waters 490 E Programable Multiwavelength Detector was used. Atrazine's retention time was approximately 4.5 min under these conditions with a detection limit of approximately 0.16 mg/l. A Waters 717 plus Autosampler was used and the system was controlled by Millennium software.

2.5. Data analysis

Measured atrazine concentrations (HPLC values) were converted into mass of atrazine found in the leachate, 0–1 cm, or 9–10 cm layer. These values were then divided by the mass of the applied atrazine to estimate the percentage of applied atrazine that was recovered in each zone. Data analysis was performed using recoveries based on percent of applied atrazine because the atrazine application rate varied slightly for the different T_{Leach} tests. As previously described, equal amounts of atrazine was applied to all of the columns leached for the same duration.

3. Results and discussion

The average volume (V_{Leach}) of, and atrazine recovery (R_{Leach}) from, the leachate for each leach test time (T_{Leach}) are provided in Table 1. The average, standard deviation, and coefficient of variation (CV) for V_{Leach} and R_{Leach} from all of the immediate and delayed columns are also shown. The average V_{Leach} for each of the tests range from 1.2 to 1.4 of the predicted pore volumes. V_{Leach} from the immediate columns appears to be slightly higher than from the delayed columns for most T_{Leach} tests. After dosing, the delayed columns were stored with their upper surface open, exposed to room air

Table 1
Average leachate volume (V_{Leach}) and atrazine recovery (R_{Leach})

T_{Leach} [h]	Immediate leach [h]		Delayed leach [ml]	
	V_{Leach} [ml]	R_{Leach} [%]	V_{Leach} [ml]	R_{Leach} [%]
0.28	32.9	26.0	28.5	15.4
0.80	34.3	22.1	30.0	14.9
1.80	32.5	23.3	31.0	19.2
5.50	32.0	23.6	32.6	16.7
Average	32.9	23.8	30.5	16.5
Standard deviation	1.0	1.6	1.7	1.9
CV	2.9	6.9	5.7	11.5

(about 25 °C). It is possible that the moisture content of these columns was reduced during this time. If so, the first few drops of infiltration water may have been held by the surface soil, leading to the typically lower leachate volumes from the delayed columns.

Typically the average atrazine recovery was about 30% less in the leachate from the delayed columns compared to the immediate columns. For both groups, atrazine recovery does not appear to be dependent on leach time. For the columns leached immediately after dosing, 23.8% of the applied atrazine was recovered in the leachate, while 16.5% was recovered from the delayed columns. The reduction in R_{Leach} for the delayed columns is much greater than the reduction in V_{Leach}; and is due primarily to a reduction in the atrazine concentration in the leachate.

Vinten et al. (1983) demonstrated that DDT and paraquat, both strongly sorbed by soils, could be leached to greater than expected depths in column experiments while sorbed to suspended colloid material. They theorized that pesticides applied as wettable powders might also be transported through the soil in suspension form for infiltration occurring soon after application. It may be possible that the high recovery of atrazine in the leachate of the immediate columns was influenced by the presence of the surfactants used in the commercial formulation. It may be that a short delay period is necessary for the atrazine to fully dissociate from the surfactants and sorb or precipitate onto the surface soil layer.

The variability in leachate volume (CV of average volume) was slightly higher for the columns where infiltration occurred 2 d after the columns were dosed with Aatrex-atrazine (delayed leach tests) compared to the columns where infiltration occurred immediately after dosing (immediate leach tests). However the variability does not appear to depend on infiltration time for either set of columns. The variability in atrazine recovery from the leachate is slightly higher for the delayed columns; but it also does not appear to depend on infiltration time for either group.

The average, standard deviation and CV of V_{Leach} and R_{Leach} for each T_{Leach} are shown in Table 2. For the immediate columns variability in atrazine recovery (as indicated by the CV) ranges from 14.5% to 29.3%, the average was 20.8% for the four leach times tested. The variability in the average recovery for the four leach times was 6.9% (Table 1). The variability in atrazine recovery from the four tests performed at each leach time was greater than the variability between the average recovery for each of the leach times tested. This suggests that for leach times from 17 min to 5.5 h (infiltration rates between 26.8 and 1.4 cm/h), the amount of atrazine transported from a freshly dosed soil surface will likely depend more on the interaction of Aatrex-atrazine solution with the soil than the rainfall intensity for transport occurring under MVE conditions. This relationship is not apparent in the delayed columns. The average CV of R_{Leach} for those four leach tests was 11.7% (Table 2) while the CV of the average recovery for the four tests was 11.5% (Table 1).

Data in Table 3 compares the average measured atrazine recovery in the upper (R_{Upper}) and lower (R_{Lower}) soil layers, leachate (R_{Leach}), and the sum of the atrazine recovery measured at these three locations (R_{Sum}) for each T_{Leach}. For both the immediate and delayed columns the average R_{Sum} across T_{Leach} is 37%, and appears to decrease with increasing T_{Leach}. The ratio of $R\_{\text{sum}}_{\text{Immediate}}$ to $R\_{\text{sum}}_{\text{Delayed}}$ is approximately unity. This suggests that atrazine did not dissipate from the column's soil surface significantly during the 2-d delay

period. However the delay clearly affected the distribution of atrazine in the column soil and leachate.

The measured recoveries follow the same trend for the immediate and delayed tests. R_{Leach} for both 'fast' and 'slow' conditions are almost within the same range. R_{Upper} is higher for 'fast' infiltration than 'slow'. R_{Lower} is higher for 'slow' infiltration than 'fast'. It is evident that more atrazine was transported from the surface soil under 'slow' infiltration conditions. However, it is not possible to identify if this transport was due to a consistently higher concentration of atrazine in the infiltrating solution or if the majority of atrazine transport occurred during the first few minutes of infiltration. It is also not possible to identify if the smaller R_{Lower} under 'fast' infiltration was due to the reduced amount of time that the infiltrating solution had to react with the lower soil layer or the reduced amount of atrazine in the infiltration solution.

These results suggest that some kind of mixing may occur in the upper soil layer during infiltration. Water infiltrating at a rate in excess of 4.2 cm/h ($T_{\text{Leach}} \leqslant 1.8$ h) may proceed through the upper layer so quickly that it does not remove as much atrazine as at slower rates. The effects of this nonequilibrium condition are most noticeable for the immediate leach tests.

Isensee and Sadeghi (1997) performed leaching studies of atrazine applied to the surface of intact 20 cm deep NT soil cores under simulated rainfall conditions. Approximately 2.79 cm of rain was applied in 1.5 h ($I = 1.9$ cm/h), then 1.65 cm in 2.5 h ($I = 0.74$ cm/h), 1

Table 2
Statistics of measured average volume (V_{Leach}) and average recovery (R_{Leach}) for immediate and delayed columns

	Immediate leach tests		Delayed leach tests	
	V_{Leach} [ml]	R_{Leach} [%]	V_{Leach} [ml]	R_{Leach} [%]
$T_{Leach} = 0.28$ h				
Average	32.9	26.0	28.5	15.4
Standard deviation	0.9	3.8	0.4	2.3
CV	2.6	14.5	1.4	14.9
$T_{Leach} = 0.80$ h				
Average	34.3	22.1	30.0	14.9
Standard deviation	0.5	6.5	1.6	2.5
CV	1.4	29.3	5.4	17.0
$T_{Leach} = 1.80$ h				
Average	32.5	23.3	31.0	19.2
Standard deviation	0.6	5.4	0.0	0.6
CV	1.8	23.1	0.0	2.9
$T_{Leach} = 5.50$ h				
Average	32.0	23.6	32.6	16.7
Standard deviation	0.0	3.9	1.1	2.0
CV	0.0	16.4	3.4	11.8
Average CV of all T_{Leach} tests	1.5	20.8	2.6	11.7

Table 3
Atrazine recovery measured in soil and leachate

	T_{Leach} [h]	R_{Upper} [%]	R_{Lower} [%]	R_{Leach} [%]	R_{Sum} [%]
Immediate leach tests					
	0.28	11.76	4.02	26.04	41.82
	0.8	16.02	2.80	22.14	40.96
	1.8	6.04	4.37	23.32	33.73
	5.5	3.67	4.21	23.55	31.43
Average		9.4	3.8	23.8	37.0
Standard deviation		5.6	0.7	1.6	5.3
CV		60.0	18.7	7.0	14.0
Delayed leach tests					
	0.28	23.64	2.00	15.43	41.07
	0.8	22.88	1.87	14.87	39.62
	1.8	11.70	3.10	19.16	33.96
	5.5	12.68	3.47	16.67	32.82
Average		17.7	2.6	16.5	37.0
Standard deviation		6.4	0.8	1.9	4.8
CV		36.2	30.4	11.5	11.1

and 2 d after application respectively. Approximately 3.5 cm of leachate was collected. The average R_{Leach} was 13.6% (CV = 24%). This is interesting because of the similarity in the ratio of leachate volume collected to infiltration volume between Isensee and Sadeghi (1997) and the delayed MVE experiments, 79% and 76% respectively; and the similarity in R_{Leach}, 13.6% and 16.5%. This similarity suggests that the MVE experiments can be used to represent atrazine transport at this field site.

Sigua et al. (1993) performed leaching studies on intact (10 cm dia. by 8 cm deep) NT soil cores from this site ($0.3 < I < 1.2$ cm/h; with a 10 kPa vacuum at the column base). Atrazine recovery in leachate samples was monitored for approximately two pore volumes of leachate. They reported that the total atrazine recovery measured in the leachate showed a strong relationship with infiltration. R_{Leach} increased with I for up to two pore volumes of leachate. Possible reasons for the difference between Sigua et al. (1993) and these MVE experiments include: (1) volume of leachate collected; (2) basic differences in how water infiltrates using the MVE compared to rain simulation experiments (Sigua et al., 1993); (3) differences between how water infiltrates through homogeneous packed columns compared to intact cores; (4) the lower infiltration rates used by Sigua et al. (1993); and (5) presence of surfactants contained in the Aatrex-atrazine formulation compared to the technical grade atrazine applied in methanol (infiltration occurred 24 h after application).

Table 4 shows the atrazine recovered in the leachate per depth of water infiltrated through the intact core or packed soil column. This comparison shows that the atrazine recovery from the intact cores was almost twice

Table 4
Ratio of measured atrazine recovery in leachate [%] to infiltration volume per surface area [cm]

	Atrazine recovery in leachate/infiltration depth [%/cm]		
	Sigua et al. (1993)	Immediate	Delayed
Infiltration rate [cm/h]			
0.3	5.0		
0.6	6.4		
0.9	7.7		
1.2	7.9		
(T_{Leach} = 5.5 h) 1.36		3.1	2.2
(T_{Leach} = 1.8 h) 4.17		3.1	2.6
(T_{Leach} = 0.8 h) 9.38		3.0	2.0
(T_{Leach} = 5.5 h) 26.80		3.5	2.1
Infiltration depth [cm]		7.5	7.5

that from the packed soil columns when normalized by infiltration volume.

Sigua et al. (1993) attributed the high atrazine transport during the first pore volume to macropores inherent in the intact cores. This was due to the observed presence of macropores in the cores and the atrazine recovery vs. leachate volume consistent with macropore flow. Therefore, the results of Sigua et al. (1993) may be considered representative of atrazine recovery expected in the leachate at a depth of 8 cm, under macroporous field conditions. The results of the MVE experiments may illustrate the chemical relationships between the atrazine, infiltrating water, and soil materials expected under matrix flow conditions.

The immediate and delayed columns for the MVE leach tests were carefully packed with soil, from the same site, to avoid creation of macropores. Therefore it's possible that the recovery from these columns represents the recovery likely under matrix flow conditions. Furthermore, the difference between the leachate recovery measured in the intact cores and the delayed columns for similar infiltration rates, may represent the actual contribution of macropore flow to atrazine transport under field conditions. Consider the average recovery from intact cores with infiltration rates of 0.9 and 1.2 cm/h (7.8%/cm rainfall), and that from the delayed columns with an infiltration rate of 1.36 and 4.17 cm/h (2.4%/cm). The difference between the two is 5.4%/cm. This suggests that during the first infiltration event, shortly after atrazine application to the field, for each 1 cm of infiltrating water 5.4% of the applied atrazine will be carried through the 0–10 cm soil horizon into the subsoil, and possibly to the underlying aquifer.

4. Conclusions

Atrazine transport through packed 10 cm soil columns representative of the 0–10 cm soil horizon of the ARS Southfarm research area was observed by measuring the atrazine recovery in the total leachate volume, the upper soil layer, and the lower soil layer following the infiltration of 7.5 cm of water using the MVE. The results indicate that for the infiltration rates tested (1.36–26.8 cm/h) atrazine recovery in the leachate was unrelated to infiltration rate. However, atrazine recovery in the leachate was significantly higher in the columns tested immediately after atrazine application to the soil surface (Table 1, average $R_{Leach} = 23.8\%$) compared to that measured following a 2-d delay (average $R_{Leach} = 16.5\%$). The sum of atrazine recovery in the three measurement locations appears to be independent of the delay, suggesting that negligible atrazine dissipation occurred during the delay period.

Atrazine recovery in both the upper and lower soil layers appears to be dependent on both infiltration rate and the delay time. For both the immediate and 2-d delayed tests, the atrazine recovery tended to decrease in the upper soil layer and increase in the lower soil layer as T_{Leach} increased from 0.28 to 5.5 h (infiltration rates of 26.8 to 1.36 cm/h respectively). In addition, the recovery in the upper soil layer was higher for the delayed tests at each infiltration rate; while in the lower soil layer it was lower for the delayed tests at each infiltration rate. This suggests that atrazine distribution in the soil profile is somewhat dependent on the infiltration rate and delay time.

The ratio of R_{Lower} to R_{Leach} is very similar for the immediate and delayed columns, and tends to increase with increasing T_{Leach}. This suggests that the strength of

sorption of the atrazine to the upper soil may increase with the 2-d delay, but the sorption characteristics of dissolved atrazine to the lower soil does not change significantly with the delay. In addition, sorption of atrazine to the lower soil does appear to be reduced by increasing infiltration rate; approximately 28% or 38% as the infiltration rate is increase from 1.36 to 26.8 cm/h for the immediate and delayed tests respectively. However considering the most likely field infiltration rates, 1.36–4.17 cm/h ($T_{Leach} = 5.5$ and 1.8 h), the differences are smaller and more difficult to interpret. Most likely there is no significant difference between the ratios for the immediate or delayed tests at the lower infiltration rates. Therefore the difference in R_{Leach} between the immediate and delayed tests is likely due to the reduction in the amount of atrazine that is mobilized by the infiltrating water from the upper soil layer. This suggests that for modeling applications it will be most important to describe the atrazine sorption and mobilization characteristics in the upper soil layer.

Under field conditions atrazine leaching below the 10 cm depth would be expected to depend more on the delay time between application and the infiltration event, than on the intensity of the event. However atrazine distribution within the 0–10 cm soil profile would be expected to depend both on delay time and infiltration intensity. It is possible that the leaching potential and characteristics of atrazine transport in subsequent infiltration events would depend on the atrazine distribution resulting from the initial infiltration event, especially if the initial infiltration occurred within the first few days after application.

Under MVE infiltration conditions ponding of infiltrating water on the soil surface does not occur. Infiltrating water is drawn through the soil column in a manner that causes the entire soil column to become saturated, but water never pools on the surface or in column void spaces. The difference in atrazine recovery between MVE experiments and other leaching experiments using intact soil cores from this field site and the rain simulation equipment probably illustrates the effect of infiltrating water interacting with the atrazine present on the soil surface. It appears that mobilization of atrazine from the soil surface is dependent on interactions of the infiltrating water with the soil surface, not just the rate of infiltration through the surface soil.

Acknowledgements

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